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DETECTION OF SALINE SOILS IN CAMERON COUNTY, TEXAS, WITH SKYLAB IMAGERY AND MULTISPECTRAL SCANNER DATA

A. J. Richardson, A. H. Gerbermann, H. W. Gausman, J. A. Cuellar, R. W. Leamer, and J. H. Everitt

ABSTRACT

The feasibility of detecting saline soils (eight areas of low, medium, and high salinity levels) in Cameron County, Texas, with SKYLAB S190B Earth Terrain Camera Imagery (SO-242 color and EK-3414 black-and-white films) and S192 multispectral scanner (MSS) data was tested.

Scan lines of film density readings, for bare soil only, from aerial color and black-and-white film were randomly selected for statistical analysis. Blocks of MSS digital data from bare soil and vegetation, for each of the 13 MSS bands (0.41 to 12.5 μm), were selected from each saline area for statistical analysis.

Neither film mean optical density readings nor S192 MSS digital data from bare soil only could be related to salinity levels using Duncan's Multiple Range Test or correlation analysis. However, the correlations of S192 MSS digital data differences between vegetated and bare soil areas (i.e., the contrast of S192 MSS data between vegetated and bare soil areas) with salinity levels from the eight saline areas using MSS bands 7 (0.78 to 0.88 μm) and 10 (1.2 to 1.3 μm) in the infrared region of the spectrum were significant (r equal -0.946 and -0.963, respectively).

Thus detection of saline soils may be possible, using either film density readings or S192 MSS data, when the lower reflectance of vegetation on highly saline soil and the higher reflectance of vegetation on lower saline soil is considered by using film or MSS contrasts between vegetation and bare soil.

Prentice[3] demonstrated that airborne thermal and spectral data could be used to detect and delineate conditions indicative of salinity and of rising water tables. Thermal contouring permitted mapping distributions of surface soil moisture, and spectral data could be used to identify various stages of salt-stressed vegetation and wet soils.

Colwell[2] reported that high flight photography and ERTS-1 satellite imagery, particularly band 5, are useful and accurate in detecting and delineating the areal extent of saline deposits that are difficult to measure from field surveys and that the additional resolution afforded by SKYLAB color photography makes possible a mapping accuracy approaching that obtained using high altitude, 1:120,000 scale photography.

This paper presents studies on the feasibility of detecting saline soils in Cameron County, Texas, with SKYLAB S190B Earth Terrain Camera imagery and S192 multispectral scanner (MSS) data.

MATERIALS AND METHODS

SOIL PROCEDURES

The following soil types occur in the Cameron County saline study site; sandy clay loam, clay loam, fine sandy loam, clay, silty clay, and silty clay loam. These soils were sampled, oven-dried, and passed through a 2-mm sieve. Their particle size distribution was made according to the Bouyoucos[1] method, and their salinity levels were determined by making electrical conductivity readings (ECe) on saturated soil extracts[4] for areas A to E running north to south along Paredes Road, and for areas F to G running west to east along Farm Road 510 (Fig. 1).

Because there was poor correlation between conductivity readings and particle size distribution, which determines soil type, the test site was arbitrarily divided in areas (eight areas from A through H) of low, medium, and high salinity levels based on ECe readings.

FILM DENSITY READINGS

Film density readings were made with a Joyce Loebl and Company* (England) microdensitometer equipped with an automatic scanning attachment made by Tech/Ops (Burlington, Mass. USA). Density readings were made on aerial color SO-242 (December 5, 1973) and on black-and-white EK-3414 films (November 29, 1973) from S190B Earth Terrain Camera (ETC)

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* Mention of company or trademark is for the readers' benefit and does not constitute endorsement of a particular product by the U. S. Department of Agriculture over others that may be commercially available.

imagery. Color film density readings were made with four different lights: white (no filter), red (Wratten 92 filter), green (Wratten 93 filter), and blue (Wratten 94 filter). Black-and-white film density readings were made with white light only. Each density reading represents the density of 0.0015 square mm of film, and readings were made at 100 per 2.54 mm on the films.

The various saline areas within the site were located on an isodensitracing (gray map) of each film type. Twelve scan lines were made across the study site on the color film, and 24 scan lines were made on the black-and-white film. Six and nine lines, from bare soil only, for color and black-and-white films, respectively, were randomly selected for use in the analysis of variance (ANOV).

Density readings from the saline areas were grouped by scan line, area, color light density, and film type and read into a computer by areas. Unusually high or low density readings caused by clouds or man-made objects were eliminated from the analyses.

The mean density readings for each scan line within each saline area were used as replications for ANOV tests of the null hypothesis of no difference among saline areas. For the color film, an ANOV was calculated for each color light density; one ANOV was calculated for the black-and-white film. The partitioning of degrees of freedom for the color and the black-and-white films are shown in Table 2. The color film had one less saline area than the black-and-white film because one area (E) was obscured by clouds (Fig. 1). Duncan's Multiple Range Test (DMRT) was used to make all possible mean comparisons among saline areas.

Linear correlation analysis relating soil salinity levels (ECe) to the mean optical densities were calculated for the color and the black-and-white films. Correlations were determined for salinity areas A, B, C, D, F, G, and H (N = 7; Figure 1).

MULTISPECTRAL SCANNER DIGITAL DATA

Computer compatible digital tapes (CCT) of the SKYLAB S192 13-band multispectral scanner (MSS) were obtained for the December 5, 1973, overpass of the saline soil areas in Cameron County. The SKYLAB S192 MSS covers the 0.41 to 12.5 μm spectral region as shown below:

Band number	Spectral region (μm)	Band number	Spectral region (μm)
1	0.41 - 0.46	8	0.98 - 1.08
2	0.46 - 0.51	9	1.09 - 1.19
3	0.52 - 0.55	10	1.2 - 1.3
4	0.56 - 0.61	11	1.55 - 1.75
5	0.62 - 0.67	12	2.1 - 2.35
6	0.69 - 0.76	13	10.2 -12.5
7	0.78 - 0.88		

Threshold values, using band 7 (0.78 - 0.88 μm) MSS digital data, were determined for distinguishing among cloud shadows, water, bare soil, vegetation, and cloud categories. These threshold values permitted studies of salinity effects on bare soil and vegetation categories separately and also permitted editing out CCT digital values in all 13-bands due to cloud shadows, water, and clouds. The rationale was that the reflectance contrast between bare soil and vegetation (i.e., S192 MSS digital value difference or ratio between bare soil and vegetation) should be a better indicator of salinity effects than bare soil or vegetation individually.

Electrical conductivity readings are probably more representative of bare soil areas than vegetation areas because most soil samples taken for ECe determination were from bare soil areas. But it was felt that vegetative areas nearest to the soil sample locations might be better indicators of salinity effects than the bare soil areas since the native vegetation population density would be affected by soil salinity.

A line printer gray map, using band 7, was used to locate the various saline areas in the study site. Each cloud free saline soil area (Fig. 1) was divided into seven blocks located sequentially along the Paredes Road (north-south direction) and Farm Road 510 (east-west direction). The mean digital value for all 13 bands of the S192 MSS for each block (7 cloud free saline areas X 7 blocks/saline area = 49 blocks) was calculated for bare soil and vegetation categories separately.

The mean MSS digital values for each block within each saline area were used as replications for ANOV tests of the null hypotheses of no difference among saline areas. There were 13 ANOV's determined, one for each of the 13 bands of the S192 MSS for bare soil and vegetation categories separately (2 categories X 13 bands = 26 ANOV's). The partitioning of the degrees of freedom for these ANOV's is shown in Table 1. The S192 MSS digital data had one less saline area than the black-and-white film, because one area (E) was obscured by clouds. Duncan's Multiple Range Test was used to make all possible mean comparisons among saline areas.

Linear correlation analysis relating soil salinity levels (ECe) to the difference and ratio between bare soil and vegetation S192 MSS digital treatment means for all 13 MSS bands were determined. Correlation analyses were also determined for bare soil and vegetation individual for comparison to correlations of bare soil and vegetation differences and ratios.

RESULTS AND DISCUSSION

SALINE SOIL AREAS

Table 2 gives the relative salinity levels and the ECe values of the study area. Also shown are the length of each area in miles and the number of soil samples that were taken within each area. Number of soil samples differed among areas because some areas contained more soil series than other areas, and soil samples were taken of each soil series.

FILM DENSITY RESULTS

There were statistically significant differences among saline areas, according to Duncan's Multiple Range Test (Table 3), for mean density readings taken with white, red, green, and blue lights for the color film and white light for the black-and-white film. However, a relation of salinity levels for the saline areas with mean density readings cannot be established. For example: (1) Areas B, C, and D with respective salinity levels of high, low, and medium were statistically alike for

white and red lights with the color film, (2) areas A and B with respective salinity levels of low and high were statistically alike for the green light with color film, (3) all areas were statistically alike for the blue light with color film, and (4) areas E, F, and G with respective salinity levels of low, low, and high were statistically alike for the white light with black-and-white film. As a result of examining the film transparencies, it was found that mean density readings were related to the lightness or darkness of the soils located within the study site.

Linear correlation analysis confirmed previous findings that soil salinity relation with film optical density measurements was poor (Table 3). Correlations using salinity areas A, B, C, D, F, G, and H ($N = 7$) were not significant (r ranged from 0.073 to -0.286). Graphically, none of the saline areas deviated from the linear correlation relationship significantly, thus none of the areas could be justifiably deleted from the analysis.

MULTISPECTRAL SCANNER RESULTS

SKYLAB S192 MSS band 7 (0.78 - 0.88 μm) was chosen, from visual interpretation of S192 MSS data displayed on a cathode ray tube, as giving the best contrast between bare soil and vegetation. The S192 MSS digital count (DC) threshold values of cloud shadows (10 to 20 DC range), water (4 to 20 DC range), bare soil (21 to 39 DC range), vegetation (40 to 72 DC range), and cloud (73 to 181 DC range) was determined from inspection of the digital values of samples of these categories selected from S192 MSS CCT.

Analysis of variance results showed statistically significant differences among saline areas for 12 of 13 S192 MSS bands (band 4 was not significant) using MSS digital data from bare soil areas only (Table 4). Similarly, there were statistically significant differences among saline areas for 12 of 13 S192 MSS bands (band 8 was not significant) using MSS digital data from vegetated areas only (Table 5). However, Duncan's Multiple Range Test showed that no relations existed among salinity levels with S192 MSS mean digital data from either bare soil or vegetation. Examples supporting this conclusion for bare soil MSS data (Table 4) are: (1) Areas B, C, and D with respective salinity levels of high, low, and medium were statistically alike for S192 MSS bands 5 and 7; and (2) areas A, C, D, F, and G with respective levels of low, low, medium, low, and high were statistically alike for S192 MSS bands 3, 4, 7, 8, and 10. Thus, various combinations of salinity level confusion exist within all 13 S192 MSS bands for bare soil areas.

Similarly, examples showing that no relation exists, according to DMRT, between salinity levels and S192 MSS mean digital data for vegetation (Table 5) are: (1) Areas B, C, and D with respective salinity levels of high, low, and medium were statistically alike for S192 MSS bands 3, 4, and 6 through 10, and (2) areas F, G, and H with respective salinity levels of low, high, and medium were statistically alike for S192 MSS bands 1 through 6, 8, and 10 through 12. Thus, various combinations of salinity level confusion exist within all 13 S192 MSS bands for vegetated areas.

Linear correlation analysis showed a significant relation between ECe measurements and S192 MSS digital means (Table 6), using saline areas A, B, C, D, F, G, and H. Only band 9 yielded a statistically significant correlation coefficient (r = 0.670) using S192 MSS data from bare soil areas. Bands 6, 7, 10, and 12 yielded statistically significant correlation coefficients using vegetation S192 MSS data (r = -0.597, -0.656, -0.548, and -0.567, respectively). Neither the difference nor the ratio of vegetation with bare soil produced large correlation coefficients. Even though some of these coefficients were significant, they were too small to be conclusive. It was found that saline area H deviated significantly from the linear correlation equation so it was deleted from the analysis.

Using saline areas A, B, C, D, F, and G (N = 6), it was found that all correlations relating saline effects to S192 MSS data improved (Table 6). There were 2 of 13 S192 MSS bands for bare soil areas that were significant (r equal 0.588 and 0.936 for band 2 and 9, respectively) s compared to 5 of 13 bands for vegetal areas (r equal -0.623, -0.929, -0.760, -0.626, and -0.649 for bands 6, 7, 10, 11, and 12, respectively). Thus vegetal areas appear to be better indicators of salinity effects than bare soil areas. Also the negative vegetal correlation coefficients [illegible] that increasing amounts of salinity decrease reflectance from vegetal areas as was expected. The reason for the decrease in vegetal reflectance with increasing salinity is probably due to stunted vegetal growth or reduced plant population density or both.

The two highest correlation coefficients were found using the reflectance difference between vegetation and bare soil using S192 MSS bands 7 and 10 (r equal -0.946 and -0.963, respectively) that are in the infrared region (0.78 to 0.88 μm and 1.2 to 1.3 μm, respectively). Thus, since 6 of 13 S192 MSS bands were significant, these correlation coefficients show that S192 MSS data differences between vegetal and bare soil areas are better indicators of saline effects than either bare soil or vegetal areas individually.

FILM DENSITY AND MULTISPECTRAL SCANNER COMPARISON

Correlation analysis showed that neither film optical density measurements nor S192 MSS data, from bare soil only, were very well correlated with ECe measurements. Density reading correlation coefficients, from bare soil only (Table 3), ranged from 0.073 to -0.286 with none of the fine coefficients being significant, while the S192 MSS correlation coefficients, from bare soil only (Table 6), ranged from 0.000 to 0.936 with 3 of 26 being significant. If density readings had been segregated into both bare soil and vegetation categories, then film density readings may have been better related to salinity effects.

CONCLUSIONS

Saline soil areas selected in Cameron County with low, medium, and high salinity levels cannot be distinguished, according to Duncan's Multiple Range Test and correlation analysis, by using film density readings made for bare soil only on SO-242 aerial color and on EK-3414 aerial black-and-white films exposed in the S190B Earth Terrain Camera or for S192 MSS digital data taken from bare soil only. However, when vegetation was also considered, correlation analysis indicated that the difference of S192 data from vegetated and bare soil areas, showing the contrast of vegetation and bare soil, was significantly correlated to salinity effects. Thus, the S192 MSS digital data differences between vegetation and bare soil, in the infrared spectral region, should provide a useful saline soil detection scheme.

Further research may show that film optical density difference between vegetation and bare soil may be related to salinity effects. More research is needed in relating mean density readings to lightness or darkness of soils because in some parts of South Texas, as well in some other arid areas of the United States, saline areas show frequently as white alkali crusts. Multivariate analysis, using two or more MSS bands, should be studied as a way of improving saline soil detection.

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Table 1. Partitioning of degrees of freedom for S190B Earth Terrain Camera color and black-and-white films and S192 MSS ANOV of soil saline study in Cameron County.

ANOV - Source of variation	S190B Color film (12/5/73) df	S190B Black-and-white (11/29/73) df	S192 MSS (12/5/73) df
Saline areas	6	7	6
Replications	5	8	6
Error	30	56	36
Total	41	71	48

Table 2. Relative salinity levels and corresponding range of electrical conductivity (ECe) readings of the saturated soil extract and mean electrical conductivity readings and their standard deviations (SD) in mmhos/cm for areas A to E running north to south along Paredes Road and for areas F to G running west to east along Farm Road 510. Also shown are the length of each area in miles and the number of samples that were taken within each area.

Area	Length of area in miles [a/]	No. of samples	Electrical conductivity (ECe) in mmhos/cm Range	Mean±SD	Relative salinity level
			Paredes Road (north to south)		
A	12.8	34	0.7- 8.2	1.9 ± 1.6	Low
B	1.6	4	11.0-27.0	20.1 ± 7.2	High
C	2.3	4	1.4- 2.2	1.6 ± 0.4	Low
D	7.0	6	6.4-22.5	13.9 ± 7.4	Medium
E	2.8	5	0.8- 1.7	1.3 ± 0.4	Low
			Farm Road 510 (west to east)		
F	4.1	16	0.6-12.6	3.6 ± 3.6	Low
G	1.8	6	10.4-65.0	40.9 ±19.6	High
H	3.7	4	9.0-14.2	11.8 ± 2.3	Medium

[a/] Width among areas is variable because of nonuniformity in size and shape of the soil series from which samples were taken.

Table 3. Duncan's Multiple Range Test among mean film densities of saline soil areas using microdensitometer readings with white, red, green, and blue light on SO-242 aerial color and white light on EK-3414 black-and-white films exposed in the Earth Terrain Camera (S190B). Means followed by a common letter are not significantly different at the 5 percent probability level. Simple linear correlation coefficients relating salinity measurements to means are also given.

Saline area	Relative salinity level	Color film (12/5/73) White light	Red light	Green light	Blue light	Black-and-white film (11/29/73) White light
		Mean film densities				
A	Low	57a	72a	57ab	46a	77a
B	High	51 b	68 b	58 b	43a	80a
C	Low	54 b	63 b	51 c	46a	75 b
D	Medium	48 b	62 b	51 c	47a	64 c
E	Low	--	--	--	--	78a
F	Low	57a	75a	57ab	48a	78a
G	High	53 b	71a	56ab	49a	80a
H	Medium	46 b	63 b	46 c	43a	76 b
		Correlation coefficients				
Saline areas A, B, C, D F, G, and H related with:		-0.286	0.073	0.172	0.248	0.241

Table 4. Duncan's Multiple Range Test among seven saline areas, using SKYLAB S192 13-band MSS mean digital data from bare soil areas only, selected in Cameron County with low (L), medium (M), and high (H) salinity levels on December 5, 1973. Channels for which analysis of variance tests indicated significant differences (p = 0.05, *; p = 0.01, **) are marked. Means followed by a common letter are not significantly different at the 5 percent probability level.

Saline area	Electrical conductivity (ECe) in mmhos/cm	SKYLAB S192 13-BAND MSS NUMBERS						
		1**	2**	3**	4	5**	6**	7**
		Mean digital values						
A	L(1.9)	48 bc	83 d	43 bc	24 b	30 bc	44 bc	29 c
B	H(20.1)	47 c	85 c	45 b	29a	31abc	46 b	31 b
C	L(1.6)	51a	81 de	42 c	25 b	33a	43 cd	30 bc
D	M(13.9)	50a	80 c	43 c	25ab	33ab	44 bc	31 bc
E	L(1.3)	--	--	--	--	--	--	--
F	L(3.6)	47 c	83 cd	43 bc	24 b	29 c	41 d	30 bc
G	H(40.9)	47 c	85a	44 bc	23 b	29 c	41 cd	29 bc
H	M(11.8)	49ab	89 b	48a	27ab	31abc	51a	37a
		8**	9**	10**	11**	12*	13**	
		Mean digital values						
A	L(1.9)	38 b	43 b	44 bc	44a	40a	133 bc	--
B	H(20.1)	46a	44 b	45 b	42ab	35ab	135ab	--
C	L(1.6)	39 b	42 b	42 bc	40ab	36ab	134ab	--
D	M(13.9)	39 b	43 b	40 c	35 c	30 b	130 c	--
E	L(1.3)	--	--	--	--	--	--	--
F	L(3.6)	39 b	42 b	42 bc	39 bc	34ab	135ab	--
G	H(40.9)	38 b	51a	43 bc	42ab	38a	136a	--
H	M(11.8)	49a	52a	53a	43ab	36ab	134ab	--

Table 5. Duncan's Multiple Range Test among seven saline areas, using SKYLAB S192 13-band MSS mean digital data from vegetation areas only, selected in Cameron County with low (L), medium (M), and high (H) salinity levels on December 5, 1973. Channels for which analysis of variance tests indicated significant differences (p = 0.05, *; p = 0.01, **) are marked. Means followed by a common letter are not significantly different at the 5 percent probability level.

Saline area	Electrical conductivity (ECe) in mmhos/cm	SKYLAB S192 13-BAND MSS NUMBERS						
		1**	2**	3**	4**	5**	6**	7*
		Mean digital values						
A	L(1.9)	48 bc	85 c	47 bc	27 bc	33 bc	60a	48abc
B	H(20.1)	51 b	94ab	50ab	34a	37 b	57ab	47abc
C	L(1.6)	57a	98a	51a	33a	42a	60a	48a
D	M(13.9)	52 b	86 c	49ab	31ab	37ab	59a	48ab
E	L(1.3)	--	--	--	--	--	--	--
F	L(3.6)	50 bc	88 bc	45 c	27 bc	31 c	53 b	48a
G	H(40.9)	47 c	84 c	45 c	25 c	30 c	52 b	44 bc
H	M(11.8)	49 bc	86 c	48abc	27 bc	34 bc	55ab	44 c
		8	9*	10*	11**	12**	13**	--
		Mean digital values						
A	L(1.9)	60ab	63a	64a	51ab	37 bc	130 bc	--
B	H(20.1)	65a	60ab	62abc	51ab	39ab	137ab	--
C	L(1.6)	61ab	63a	63ab	52a	43a	133 bc	--
D	M(13.9)	59ab	61ab	58abc	44 c	33 cd	128 c	--
E	L(1.3)	--	--	--	--	--	--	--
F	L(3.6)	58ab	68a	61abc	47 bc	36 bcd	141a	--
G	H(40.9)	56ab	63a	58 bc	43 c	31 d	131 bc	--
H	M(11.8)	53 b	55 b	56 c	42 c	31 cd	130 bc	--

Table 6. Simple linear correlation analysis relating soil salinity levels (electrical conductivity readings) to each of bare soil (BS), vegetation (VEG), VEG-BS, and VEG/BS S192 MSS digital data. Data were collected from Paredes Road and Farm Road 510 on the December 5, 1973 SKYLAB overpass from seven saline soil areas.

S192 MSS band number	Salinity areas A, B, C, D, F, G, and H correlated with (N = 7):				Salinity areas A, B, C, D, F, and G correlated with (N = 6):			
	Bare soil (BS)	Vegetation (VEG)	VEG-BS	VEG/BS	Bare soil (BS)	Vegetation (VEG)	VEG-BS	VEG/BS
				Correlation coefficients				
1	-0.437	-0.448	-0.307	-0.294	-0.438	-0.481	-0.389	-0.376
2	0.327	-0.355	-0.428	-0.434	0.588*	-0.375	-0.527	-0.530
3	0.153	-0.357	-0.362	-0.370	0.430	-0.358	-0.456	-0.462
4	0.055	-0.250	-0.367	-0.396	0.078	-0.272	-0.505	-0.543
5	-0.357	-0.435	-0.463	-0.475	-0.354	-0.445	-0.492	-0.507
6	-0.110	-0.597*	-0.340	-0.312	-0.136	-0.623*	-0.739**	-0.727**
7	0.000	-0.656**	-0.293	-0.275	0.162	-0.929**	-0.946**	-0.865**
8	0.062	-0.259	-0.198	-0.213	0.159	-0.393	-0.862**	-0.688*
9	0.670**	-0.116	-0.455	-0.525	0.936**	-0.258	-0.876**	-0.905**
10	0.029	-0.548*	-0.277	-0.278	0.184	-0.760**	-0.963**	-0.869**
11	0.064	-0.504	-0.499	-0.479	0.083	-0.626*	-0.722**	-0.680*
12	0.050	-0.567*	-0.513	-0.503	0.051	-0.649*	-0.569	-0.566
13	0.420	-0.157	-0.374	-0.368	0.424	-0.180	-0.423	-0.416

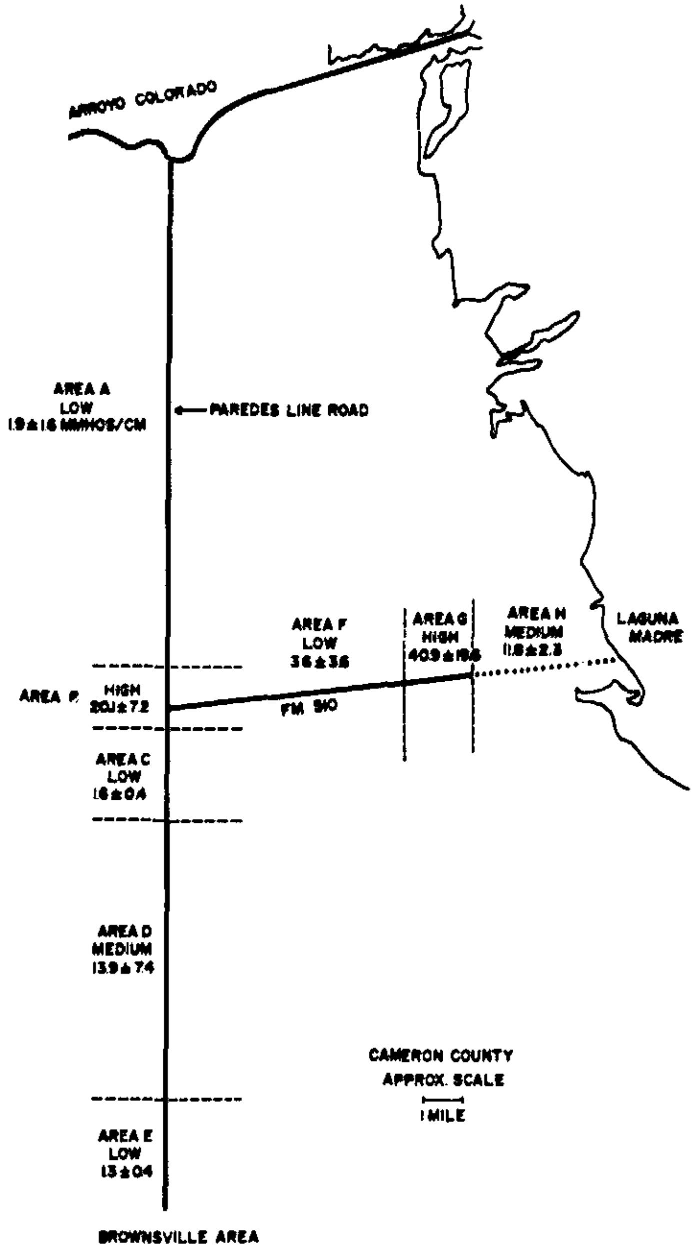

Fig. 1.--Saline soil study in Cameron County showing location of electrical conductivity measurements (mmhos/cm) for eight saline soil areas. The study site is located on Paredes Road and Farm Road 510 and was used for relating aerial color SO-242 and black-and-white film from S190B Earth Terrain Camera and S192 multispectral scanner data to salinity effects.